CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-138

October 19, 1982

1. Name of faults: Mad River fault zone (Trinidad, McKinleyville, Mad River, Fickle Hill, and related faults).

2. Location of faults: Trinidad and Crannell 7.5-minute and Eureka, Blue Lake, Iaqua Buttes, Pilot Creek, Blocksburg, Pickett Peak, Alderpoint, and Kettenpom 15-minute quadrangles, Humboldt, and Trinity Counties (Figure 1).

3. Reason for evaluation: Part of a state-wide program to evaluate Quaternary faults and zone those faults which are "sufficiently active" and "well defined" (see Hart, 1980).

4. List of references:

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Kelsey, H.M., and Allwardt, A.O., 1974, Geologic map of the Van Duzen River basin, Humboldt and Trinity Counties, California, in California Department of Water Resources, plate 8, 10 sheets, scale 1:35,200.

Manning, G.A., and Ogle, B.A., 1950, Geology of the Blue Lake quadrangle, California: California Division of Mines Bulletin 148, 36 p., 3 plates, scale 1:62,500.

McPherson, R.C., Smith, S.W., and Severy, N.I., 1981, The Humboldt Bay seismic network, 1974-1980: Earthquake Notes, Eastern Section, Seismological Society of America, v. 52, m. 1, p. 41-42.

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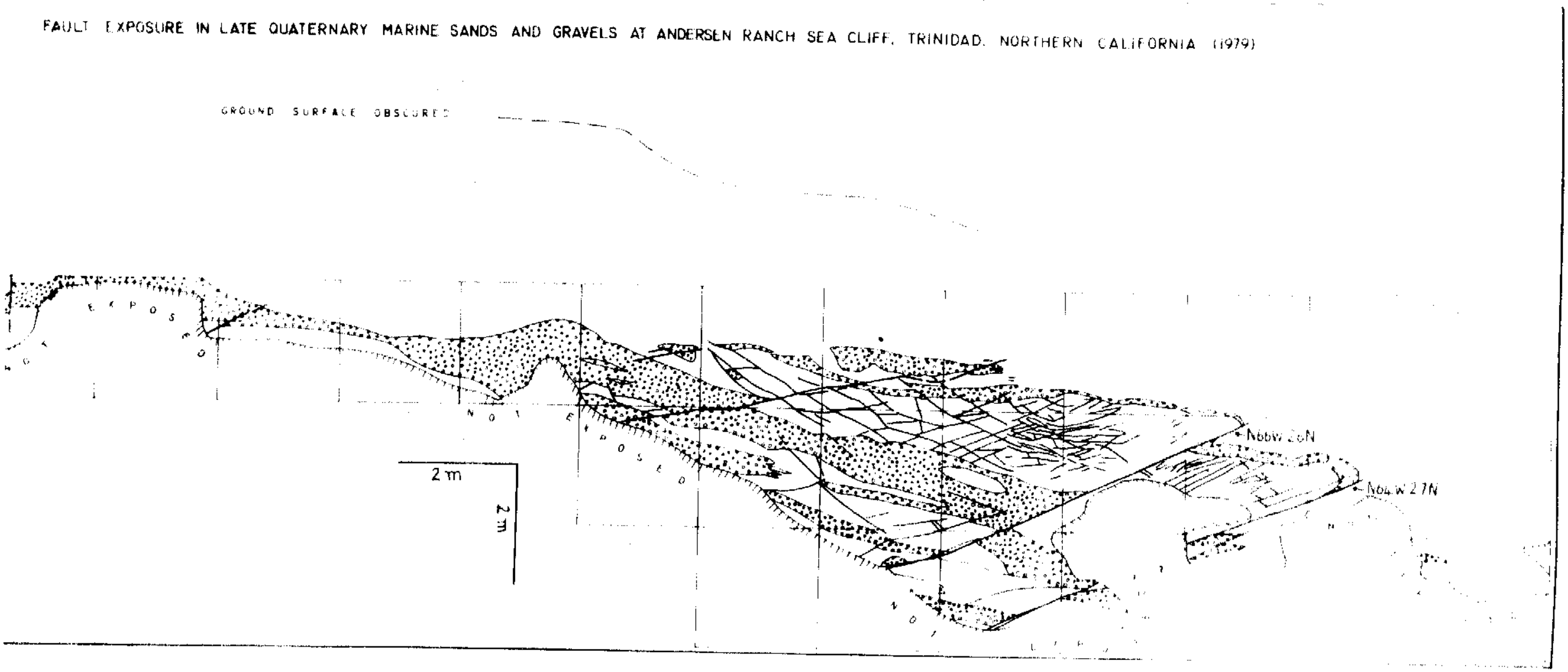
5. Summary of available data:

About 1976, Earth Sciences Associates postulated the existence of a major zone of northwest trending faults which they named the Mad River fault zone. They stated, "The onshore part of the zone near Humboldt Bay shows evidence of late Quaternary tectonism including faulting and warping of marine terrace surfaces ...". They also attributed a M6.5 earthquake (the 1954 Freshwater earthquake) to this zone. Their regional fault map (scale 1:250,000) showed the Mad River fault zone as extending from northwest of the McKinleyville airport southeastward to the Round Valley Indian Reservation (Southwestern Trinity County). Although geologic maps of parts of this area existed (Manning and Ogle, 1950; Strand, 1962; Blake, 1965; Irwin and others, 1974; and Kelsey, 1975), none of these earlier maps or reports contained any indication that one or more major Quaternary faults existed in the area (Manning and Ogle, 1950, p. 28-29, do indicate that indirect evidence of possible Quaternary tectonism was present in the area, however).

Herd (1978) also concluded that a major system of faults (which he called the Hayward-Lake Mountain fault system) trended through the area. Based on the existence of landforms he considered diagnostic (sharp linear valleys and ridges, troughs, trenches, saddles, sag ponds, and east- and west-facing scarps), he concluded that two of the fault zones in this system, the McKinleyville and Lake Mountain fault zones, have been active during the late Quaternary. As further evidence, he noted that some of these features appeared youthful based on their existence in Pleistocene marine terrace deposits at McKinleyville.

In early 1979, a northeast-dipping, low angle (26°-27°) zone of thrust faults was discovered exposed in a sea cliff north of Trinidad (Figure 2) (Rust, 1982). The exposure of this fault zone, referred to as the Trinidad fault by Coppersmith (1980), Aalto and others (1981), and Carver and others (1982a; 1982b), and the Anderson Ranch fault by Rust (1982), is on trend with a very youthful-appearing scarp in the Patricks Point Terrace (Figure 3A). At the cliff exposure, the terrace sands and gravels are clearly faulted by a series of thrust faults. Total measured offset (stratigraphic throw due to faulting and folding) at this exposure amounts to roughly 21 feet, although the terrace surface appears offset about 30 feet. This discrepancy has been attributed to the limited exposure (Rust, 1982). Terrace deposits are clearly thrust over colluvial deposits along two faults (Carver, p.c.; Coppersmith, 1980), although the faults "lose their identity" before reaching the top soil horizons below the terrace surface (Rust, 1982). Numerous conjugate faults and fractures in the upper plate are exposed in this zone (Rust, 1982; Carver and others, 1982a; 1982b; Smith, this report). Coppersmith (1980) reported that two trenches excavated on the scarp nearby exposed similar thrust faults with conjugate fractures in the upper plate and exposed Franciscan rock which had been thrust over the terrace deposits. The dips of the principal faults observed in the trenches were reported as ranging from 45°E at depth to nearly horizontal near the surface. Where trenched, the zone of deformation ranged from about 15 to 70 feet, with the cumulative displacement (net dip-slip) totalling about 45 feet. (Rust reports the maximum scarp height as about 50 feet, but that part of this total may have resulted from shoreline erosion.)

The age of the Patricks Point terrace is not precisely known but has been estimated based on pedology (clay content and etching of hornblende). Coppersmith (1980) estimates the terrace to be about 82,000 years old (range: 60,000 to 105,000 years) while Stevens (1982) estimates the age as about 100,000 years old (range: 68,000 to 130,000 years).



FER-138. Figure 2. Log of fault exposure at Anderson Ranch (Trinidad fault). Log from Rust, 1982.

Based on the 82,000 year date, and assuming that the entire offset (2.5 to 3.0 m) of the colluvium occurred in a single event, Coppersmith (1980) estimated a recurrence interval of 6,000 to 8,000 years along the Trinidad fault (0.3 to 0.5 mm/yr rate of displacement).

Rust (1982) noted several lines of indirect evidence of recent movement along the Trinidad fault:

1. a sag pond behind the scarp at Anderson Ranch which was apparently produced by a drag folding of the terrace surface;
2. convex profiles of several, apparently oversteepened, streams (including one nick-point on Indian Creek);
3. a ponded drainage along College Cove Creek (which Rust interprets as a sag pond produced by faulting and folding); and,
4. the warping of Luffenholz terrace (inferred to be about 60,000 years old by Rust) adjacent to the fault.

Rust has not been able to identify any post-Patricks Point terrace deposits either overlying (and not offset) or cut by the Trinidad fault. He has, however, apparently mapped the fault farther southeast than has Coppersmith (see Figure 3A).

To the south, in the vicinity of the county airport (north of McKinleyville), there exists a prominent west-facing scarp crossing a broad terrace (the upper level of the McKinleyville terrace of Weaver, 1981; tentatively correlated with the Patricks Point terrace by Coppersmith, 1980). Two trenches were excavated across the scarp on the airport grounds (Coppersmith, 1980; Figure 3B). A thrust fault (trending N45°W, 17° to 25°NE dip) was found along which Crannell sands (about 700,000 years old) were displaced over post-terrace colluvium. In addition to the primary thrust fault, the McKinleyville fault, conjugate fractures were present in the upper plate.

Some of these conjugate fractures also offset base of the colluvium. Coppersmith determined that the zone of post-terrace deformation appears confined to a 10-m wide zone at the site of the trenches.

Based on the trench data, Coppersmith concluded that at least three post-Crannell faulting events have occurred at the airport site, and that at least two of these three (or more) events occurred after the terrace formed. The latter conclusion is based on the presence of faulted, post-terrace colluvium which he assumed was derived from a fault scarp (created during the postulated first post-terrace fault rupture event).

Coppersmith assumed that the 25° dip observed in the trenches is typical of the dip of the fault at depth. Based on this assumption and the 8 m difference in elevation of the terrace platform across the fault, he estimated the net slip (actually net dip-slip) as 19m. Using bore hole data, he also estimated the net post-Crannell slip to be about 60 m. Thus, the rate of dip-slip displacement over the last 60,000 to 105,000 years is an estimated 0.2 to 0.3 mm/yr.

Coppersmith (p. B-64) notes that the trench data are inadequate to estimate recurrence, but he evaluated the morphological evidence at the trench site. He stated, "At the exploration locality, the fault is well preserved; it is apparently not dissected by first-order drainages, and the fault is located well up the scarp face, indicating little erosional back-wasting of the scarp. These data suggest it is possibly not older than Holocene, probably younger than about 20,000 years old." Using the preferred slip rate of 0.2 mm/yr, and a recurrence interval of 20,000 years, he arrived at a 4.0 m displacement per event. However, he notes the lack of any even weakly developed A-horizons, and suggests that the recurrence interval may be much shorter, perhaps about 5,000 years.

Coppersmith (p. B-52 and B-54) also prepared a lineament map of the area. However, he gave no indication whether some or all of these lineaments might be faults, except for the feature trenched and discussed above.

Weaver (1981) studied the tectonic deformation of the McKinleyville terraces. He cited the existence of two terraces, the McKinleyville terrace (the main terrace in the area which included the airport site investigated by Coppersmith) and a younger non-marine terrace, the Tyee terrace (see Fig. 3B). Weaver also made an effort to differentiate between erosional and tectonic geomorphic features. He concluded that key diagnostic features include assymetrical scarps, linear ridges (mole tracks or compressional ridges), and trough-like swales (especially fore-scarp swales). In the area he studied, he identified three apparent, principal, recently active, tectonic zones of features - the McKinleyville fault zone (trenched by Coppersmith as discussed above), the Mill Creek fault zone, and the Tyee fault zone.

Weaver described the McKinleyville zone as consisting of a 10 m-high, northwest-trending, southwest-facing scarp with a prominent, parallel fore-scarp swale. The Mill Creek zone is also marked by a 27 m-high, northwest-trending scarp with parallel forescarp swale. In the vicinity of Fisher Road, this scarp bifurcates, which he concluded, indicates that the Mill Creek fault zone consists of two or more principal faults. The Tyee zone is partially drowned by the Mad River flood plain. The Tyee terrace is approximately 13 m above the flood plain indicating in excess of 13 m of faulting and/or folding has occurred along the Tyee zone. That the Tyee terrace is folded, at least in part, has been documented near the mouth of the Mad River where the river has exposed part of a monoclinal fold and two southeast-dipping faults (Figure 4B).

Weaver also indicated that the height and expression of these scarps can vary considerably over short distances. In describing the School Road scarp (the eastern branch of the Mill Creek zone), he notes that from the site of the maximum height (11m) of the scarp it diminishes in elevation both to the north and south. "In both of these directions, the scarp changes from typical scarp morphology to the morphology more characteristic of a mole-track." He also stated that these mole-tracks end rather abruptly near Hiller Avenue to the north, and near the intersection of School Road and McKinleyville Avenue to the south.

Weaver concluded that all three of the zones of scarps are faults, citing the work of Woodward-Clyde (the McKinleyville fault zone), the existence of a waterfall at and deflection of Mill Creek (his Mill Creek zone), and the folded, faulted material at the mouth of the Mad River (the Tyee fault zone). He noted, however, that the reverse faults exposed at the river mouth are probably conjugate shears and not the principal fault.

Weaver (p. 59-60) also suggested there are other more subtle and less well-defined faults affecting the McKinleyville terrace. For example, he described the Hiller Pasture fault zone as several low, northwest-trending scarps which probably are the result of minor fracturing. He also delineated other features as probably faults based on apparently disrupted drainages. One northeast-trending fault was inferred based on apparently "offset" surfaces; however, Weaver stated this fault is not well defined and that the surfaces may not correlate with one another.

Farther inland (Figures 3B and 3C), Berry (1981) documented the existence of a 4 m high, west-facing scarp across the highest of four terraces along the Mad River near Blue Lake. Berry concluded, based on soil weathering characteristics, that all four of these terraces may be less than 40,000 years old. Although radiocarbon dating of three of these terraces was attempted, the dates obtained appear anomalously young (less than 300 years old; Carver, p.c., 1981).

Berry described the scarp as generally trending N25W (range N15W to N40W), and noted the presence of a small swale at the base of the scarp. Locally, this swale is marshy during the winter. Also, locally, the scarp possesses a "mole track" form similar to other faults already discussed. These features also were mapped by Carver and others (1982a), locally verified by this investigator, and are shown on Figure 4B.

More recently, Carver and others (1982a) attempted to compile a regional map 1:24,000 scale) of recent (Quaternary) faults in the area. They report that they identified four principal faults, the Trinidad, McKinleyville, Mad River [which includes Weaver's (1981) Mill Creek zone], and Fickle Hill, as well as a host of other faults which displace Quaternary deposits or landforms (Fig.4A, 4B and 4C). In addition to the fault maps, Carver and others (1982a) also produced a set of lineament maps (1:62,500 scale) of a larger area(noted in yellow on Figure 1; see Figures 4D through 4K).

Carver and others (1982a) identified a zone, about 10 miles wide, of closely spaced, sub-parallel lineaments along the general trend of the Mad River. This zone, which extends from the coast to the vicinity of Mount Lassic where the zone becomes indistinct, generally lies on the trends identified by ESA (c 1976) as the Mad River fault zone and by Herd (1978) as the McKinleyville and Lake Mountain fault zones. It also is on trend with several faults that appear to displace Pliocene and younger deposits offshore (Field and others, 1980).

On their fault maps, Carver and others (1982a) have distinguished between faults mapped on the basis of fault exposures (closed barb) and those mapped on the basis of geomorphic expression alone (open barb and lacking barb). These faults are annotated to a limited degree. The pattern of the faults depicted is generally NW-striking, sub-parallel, linear to slightly sinuous. They interpreted about half the lines they plotted as northeast-dipping low angle reverse or thrust faults. The remainder of the lines are "lineaments associated with geomorphic features suggestive or permissive of faulting." The report accompanying their maps includes a generalized version of the data already summarized above (principally in Coppersmith, 1980; Weaver, 1981; Berry, 1981; and Rust, 1982).

Carver and others (1982a) report that the Trinidad, McKinleyville, Mad River, and Fickle Hill faults all displace the lowermost emergent marine terraces, as do numerous smaller faults (at Patricks Creek-Dows Prairie, Strawberry Creek, Widow White Creek, and possibly Jacoby Creek). The morphology along the trend of these faults varies considerably. Features noted in terrace terrain include both rounded and locally faceted scarps accompanied by broad linear depressions, linear ridges, mole tracks, close depressions, and linear depressions. In highly dissected terrain, linear drainages, aligned saddles, side-hill ridges, linear depressions, and diverted or disrupted streams are cited along most faults they depict.

Carver and others (1982a) noted that faults observed in unconsolidated or poorly consolidated deposits typically showed evidence of small displacements along numerous closely-spaced, well-defined fractures. These fractures and faults commonly were marked by clay gouge, rotated, disrupted, and broken detrital grains and clasts, and iron oxide or manganese oxide accumulations. The typical dip of the primary set of faults was 20° to 45° NE ~~NW~~, with a conjugate set of faults and fractures dipping 20° to 45° SW ~~SE~~ in unconsolidated to weakly consolidated deposits. Where Franciscan rocks were displaced over Quaternary units, the principal faults were generally more steeply dipping. Fracture spacing ranged from less than an inch to several feet apart, with the most dense fracturing usually occurring near fault surfaces exhibiting the greatest displacement. Slickensides, common on fault surfaces where gouge is present, indicate predominantly dip-slip movement has occurred. Displaced bedding also indicates mostly reverse slip with minor normal slip documented locally. Warping or tilting of terrace surfaces is common near major faults. Early-mid Quaternary deposits are frequently nearly vertical or overturned within several hundred feet of faults having large displacements. Based on field mapping of the basal contact of the Falor Formation, it appears that a minimum of 5 km of apparent dip-slip displacement has occurred across the entire zone of thrust faults (in and near section 6, T5N, R2E, Figure 4B and 4C) in about the last 700,000 years (Carver and others, 1982b). Displacements on individual faults may locally be in excess of 3 km over this same period (Carver and others, 1982a).

Comparing the maps of Carver and others (1982a), Aalto and others (1981), Coppersmith (1980), Rust (1982), Weaver (1981), and Berry (1981) shows that they generally agree, although they may differ in detail. However, Coppersmith's (1980) maps of the Trinidad and McKinleyville faults are somewhat generalized. Rust (1982) apparently has more complete data on the location of the Trinidad fault south of the Trinidad cemetery than have any other workers (Figure 3A). However, Carver (p.c., 1982) feels that the Trinidad fault lies offshore in the area southeast of Trinidad Bay and questions whether the two youngest terraces identified by Rust are truly marine terraces (this includes the Luffenholz terrace shown on Figure 3A). Weaver (1981) contains some useful information on terraces, as does Berry(1981). Carver and others (1982) have relied heavily on Coppersmith (1980) and Berry (1981) for site-specific information, but have gone beyond earlier efforts in an attempt to analyze the faulting on a regional scale and to more completely delineate the Mad River fault zone. Based on the work of Carver and others, for example, it appears that the fault mapped by Berry as cutting a river terrace near Blue Lake may be the same fault that offsets the marine terrace at the McKinleyville airport (the McKinleyville fault).

Carver and others (1982a) identified three subparallel faults (inferred based on geomorphic features) and a lineament in the downtown Arcata area (Figure 4B). Their map indicates that two of these faults have been observed in the field. According to Carver (p.c., 1982), two faults were observed in the U.S. Highway 101 roadcut through Arcata about 1972. At that time no logs were made of the cuts by either HSU faculty or CalTrans personnel (Carver, p.c.; M. McCauley, p.c., 1982) The precise locations of these two faults, the sense of displacement, and their relationships to the geomorphic features are not documented. However, Carver and others feel it is reasonable that the geomorphic features are fault produced. The age of the deposits faulted is not known, but Carver and Tom Stephens (p.c., 1982) both feel that they may be remnants of the Patricks Point terrace or an equivalent.

A comparison of Carver and others (1982a) with the basic geologic mapping of Manning and Ogle (1950), Irwin (1974), and Kelsey and Allwardt (1975) reveals some substantial differences as well as local confirmation of the existence of faults. Carver (p.c., 1981) stated that some of the "faults" mapped by Manning and Ogle (1950) are not faults at all, but are ash beds or depositional contacts. Also, Manning and Ogle locally mapped the boundaries of landslides as faults (hence the rectalinear pattern on their 1950 map). However, he also stated that locally the fault traces mapped by Manning and Ogle coincide with the Quaternary faults identified by Carver and others (1982a) (see Figure 4E). The major structural trends shown by Irwin (1974) and Kelsey and Allwardt (1975) are generally parallel to the lineaments delineated by Carver and others, although match of precise faults and lineaments is less clear (Figures 4F - 4I).

6. Field Data

Field observations were made by this investigator during October 1981, January 1982, and September 1982. As implied by Carver and others (1982a), actual exposures of faulted materials are quite limited in the area evaluated. Also, access to several of the exposures is highly restricted. Access to some key exposures was arranged by Gary Carver, and useful discussions were held with Carver, Tom Stephens, and Casey Weaver, both in the field and in the office.

The observations of Rust (1982, included herein as Figure 2) at Anderson Ranch (Figure 4A), were partially verified in October 1981 and September 1982. The terrace deposits are clearly displaced along at least one low-angle thrust fault, and terrace gravels have clearly been displaced over post-terrace colluvium. The pattern of conjugate shears in the upper plate was also quite evident. The principal thrust faults observed at the Anderson Ranch locality appear to be on strike with the base of a well-defined scarp that crosses the Patricks Point terrace. To the southeast of Trinidad, along Trinidad Bay and Luffenholz beach, no convincing exposures of faults were observed; however, the roadcuts in this area are often covered with vegetation.

Near Crannell, a possible low mole track in the flood plain (identified as a queried fault by Carver and others, 1982) was also briefly examined in the field (Figure 4A). Although this rather subtle feature could be the result of fault movement, it might also be fluvial in origin. Similarly, the possible fault along Dows Prairie Road (Sec. 18, 19 and 20, T7N, R1E) near Little River State Beach was not very convincing. It appears to consist of a slightly curving stream and a low, discontinuous swale. I was more impresed by a low, but sharp, northeast-facing scarp to the north, located near Patrick Creek (Sec. 17 & 18, T7N, R1E; Fig.4B) and depicted as a lineament by Carver and others (1982a).

The fault scarp at the McKinleyville airport (McKinleyville fault) is quite well defined except where man-modified, and can be traced in the field with confidence southeastward to McKinleyville Avenue (formerly Redwood highway) (see Fig. 4B). From that point southeastward for about 1½ miles, there is a linear hillfront which has been interpreted by Carver and others (1982) as a fault scarp . Approximately on trend with the McKinleyville fault is a northeast-dipping fault in Quaternary sands exposed in a cut (center of sec. 15, T6N, R1E). The fault/soil relationship at this site was obscured, however.

Still further southeast (in sec. 31, T6N, R2E), along another possible branch of the McKinleyville fault, the scarp identified by Berry (1981) was verified. As she notes, the scarp averages about 12 feet in height, although locally some of this height could be due to erosion along deflected drainages. This scarp rather clearly disrupts the terrace surface, and is locally very well-defined. The hillside and terrace both slope eastward, while the scarp indicates that the eastern block has risen relative to the western block. At least one stream has cut a channel across the scarp. Based on vegetation growing along the scarp, it appears the inferred fault acts as a water barrier, at least locally.

Two well-defined, northwest trending, subparallel scarps were also verified in sec. 6, T6N, R1E (Fig. 4B). The northeasternmost of these two scarps (the School Road scarp of Weaver, 1981), is up to 30 feet high, is fairly sharp, and diminishes in height to the north and south. As its southern end, the terrace surface undulates slightly, suggesting that the fault has not cleanly propagated through the terrace deposits but has caused two or three broad folds to develop. Approximately on trend is a waterfall on Mill Creek. About 100$\pm$ feet in a downstream direction, and a few tens of feet above the streambed, a northeast dipping, low-angle fault was observed in Franciscan rock. The southwesternmost scarp (Weaver's Mill Creek scarp) was also fairly well defined, but may be partly erosional in origin.

Weaver's (1981) Tyee scarp was also verified in the field. The Mad River has cut across the north end of the scarp, exposing two apparently minor northwest dipping, high-angle faults in Quaternary deposits. These two faults are located north of a relatively broad monocline. If this monocline is the result of movement along a thrust fault, then either the fault "crops out" beneath the Mad River flood plain deposits, or it dies out as it nears the surface. No evidence of recent faulting was noted in the flood plain, but it is unlikely that such evidence would remain in light of the historic record of flooding along the Mad River.

A low linear ridge was also noted near the community of Bayside (Fig. 4B). The cause of this feature is not yet clear, but Carver and others (1982) have suggested that it might be the result of recent (probably Holocene) faulting.

Carver and others (1982a) also identified three subparallel faults and a lineament through downtown Arcata (Sec. 28, 29, 32, and 33, T6N, R1E). Locally these escarpments are well-defined, although the "lineament" is a fairly subtle scarp. The northeasternmost of these four trends is not a continuous feature, nor could it be followed as mapped by Carver and others. These features will be addressed in more detail below.

Several others lineaments and faults mapped by Carver and others (1982) were briefly examined in the field. Most of the features (e.g., swales and linear drainages) along these lineaments or faults appear permissive, at best, and may entirely result from local back tilting of the terrace surface, or may entirely be erosional in origin.

Based on field observation, the Trinidad fault, McKinleyville fault, School Road fault, and Mill Creek fault are locally well defined, and are most probably the result of fault movement although the Mill Creek scarp may be erosional in part. No convincing evidence of movement during Holocene or latest Pleistocene time was noted in the field along any other faults or lineaments in the study area.

7. Air Photo Interpretation

Air photos interpreted:

U.S. Geological Survey, 1972, Black and white aerial photographs, GS-VCZP series, roll 3, numbers 132-143, 167-175, and 186-198, scale 1:31,500.

U.S. Department of Agriculture, 1954, Black and white aerial photographs, CVL series, roll 1N, numbers 105-113; roll 2N, numbers 18-30; roll 13N, numbers 88-104; and roll 14N, numbers 23-38 and 100-117, scale 1:20,000.

Fairchild, 1964, Black and white aerial photographs, HUM series, roll 16, numbers 39-57, and roll 18, numbers 7-19, scale 1:90,000.

Three sets of aerial photographs (listed above) were viewed stereoscopically in an effort to verify and refine the work of others (principally Carver and others, 1982; Rust, 1981; Weaver, 1981; Berry, 1981; and Coppersmith, 1980). Topographic features visible along all faults shown on these references were analyzed, with the following results.

Trinidad fault:

The Trinidad fault appears on the photos as a sharply defined scarp and, locally, broad mole track. This scarp can be traced with confidence to the vicinity of the Trinidad cemetery (see especially photos CVL-1N-106 to 108). There is a suggestion of a scarp around the cemetery (section 23, Figure 4A), but south of the cemetery vegetation and the works of man make it difficult to determine just where the fault is located. The few escarpments visible along the coast could be due to coastal erosion or faulting, based solely on the air photos interpreted. However, at least some of these escarpments can be eliminated from consideration based on geologic mapping of Rust (1981).

McKinleyville fault:

The McKinleyville fault also appears on the photos as a sharply defined scarp in the vicinity of the airport, locally paralleled by a linear swale on the upthrown block (see especially photos CVL-13N-94 & 95). This scarp across the terrace takes a fairly sharp bend near the old highway and appears to coincide with the back edge of the terrace east of the golf course. From that area southeastward, there are at least two zones of possible fault-produced topographic features, as mapped by Carver and others (1982), and at least one additional zone between based solely on the air photos interpreted. Although mostly obscured by vegetation, local evidence of a relatively well-defined fault is visible on the photos. North of the Mad River, the westernmost of Carver and others two segments appears best defined, marked by scarps, linear drainages, and possible disrupted drainages. Features present along the easternmost segment are permissive of recent faulting, and lack detailed morphologic features (microtopography). The segments between the two are based primarily on fairly well-defined scarps and linear drainages.

In the vicinity of these several possible fault traces, the Mad River makes two, and possibly three, right angle bends (as in a right-lateral deflection). To the southeast, on trend with this apparent broad zone of imbricate thrust faults, is a well-defined scarp across a river terrace (verifying the work of Berry, 1981, and Carver and others, 1982). Just how this fault connects with the fault zone to the north is not entirely clear. Also, just where the fault is to the south is not clear from the photos, largely due to the dense forest cover as well as the lack of any terrace or similar geomorphic datum.

Mad River fault:

The Mad River fault (Weaver's Mill Creek and School Road faults) is marked by two sharp, high, subparallel escarpments crossing School Road (Sec 6, T6N, R1E). Sags and swales located between the two scarps as well as downslope from the Mill Creek scarp are also apparent on the photos. The Mill Creek scarp appears dissected in sec 7, and may have been partly modified by the Mad River near Azalea State Reserve (Sec 9). It appears that Carver and others (1982a) may have slightly misplotted the location of the Mill Creek scarp. To the north, the Mad River zone is not very well defined, however, a low, somewhat broader scarp was visible on the photos interpreted (again slightly east of the trace plotted by Carver and others).

South of the Mad River, not obvious fault produced geomorphic features were detected on the photographs interpreted. Several features suggestive of faulting (not necessarily recent) were noted but did not always coincide with the lineaments plotted by Carver and others.

Fickle Hill fault:

Carver and others (1982a) include the scarps through Arcata in the Fickle Hill fault zone. On the photos there are two sharply defined south-facing scarps with forescarp swales (Sec 33, T6N, R1E). These scarps appear to branch locally, and may merge into the single well-defined scarp identified to the northwest. At least two of the scarps shown by Carver and others (1982a) in Arcata were not clear on the photos interpreted. One is apparently too small to be seen in the developed area; the second (near the old hospital site) appears to be quite discontinuous. This latter "fault" may in reality be a series of erosional features that have been subsequently modified by erosion. The low scarp near city hall (on 7th Street), barely visible on the photos, apparently lacks any other type of geomorphic feature indicative of fault recent movement. An erosional origin for this feature cannot be ruled out given its proximity to the flood plain. None of these lines of scarps can be traced southeastward with any confidence, however.

Other faults and lineaments:

Carver and others (1982a) have identified numerous other faults and lineaments. All those depicted on the 1:24,000 scale maps were checked on the photos to a limited degree. Essentially, air photo interpretation is of very limited value in the forested areas and in areas lacking a well-defined geomorphic datum (e.g., a marine terrace or platform). In addition, it is apparent that low scarps observed in the field are not always visible on the photos available for interpretation.

Many of the faults and lineaments have features permissive of recent faulting located along them. However, Carver and others maps may be misleading, in part, because the features they cite do not always lie precisely where faults or lineaments are shown (that is, they may be slightly off trend or more sinuous than depicted).

Of particular interest is the "mole track" near Bayside (sec 3 & 10, T5N, R1E; Figure 4B): This feature is apparent on the photos interpreted, and appears to lie in the Jacoby Creek floodplain. This "mole track" has been partly eroded by Jacoby Creek. Indeed, the entire feature in the flood plain may be the product of Jacoby Creek and a smaller, unnamed stream.

8. Seismicity

As noted by Field and others (1980), the study area is seismically active but the type of motion associated with major earthquakes is largely unknown. Several major earthquakes have occurred in this region. Among those that appear to be located in the proper position to have been produced by a northeast-dipping thrust fault located along the zone postulated by Carver and others (1982a) are:

Date	Estimated Epicenter	Mercalli Intensity or Magnitude
30 Sept 1875	SE of Eureka	VII MM
28 Jan 1884	NE Humboldt County	V MM
30 Sept 1894	SE Humboldt County	VII MM
18 Aug 1908	40.8°N, 124.0°W	5.0
3 June 1935	41.0°N, 124.0°W	5.0
1 July 1938	41.0°N, 124.0°W	5.0
21 Dec 1954	40.8°N, 123.9°W	6.5

(Compiled from Toppozada, et al, 1981, and Real et al, 1978).

Monitoring of recent seismicity suggests that thrusting is taking place at depth beneath the study area (Carver, p.c., 1982).

9. Conclusions

At least three locally well-defined zones of late Quaternary thrust faults have been identified in the McKinleyville-Trinidad area. It appears that substantial dip-slip displacement (on the order of a few kilometers) has occurred along a rather broad (about 2 km wide) zone east of Arcata. At least two post-terrace, surface-fault displacement events have been documented on two of these three faults (the Trinidad fault and the McKinleyville fault). The third well-defined zone of faulting, the Mad River fault, has not been observed in outcrop where it is geomorphically well-defined. However, the geomorphic features locally present along all three of these zones are quite similar. Therefore, it is likely that all three zones are of about the same age (with respect to recency of movement) and represent similar relative hazards from surface fault rupture.

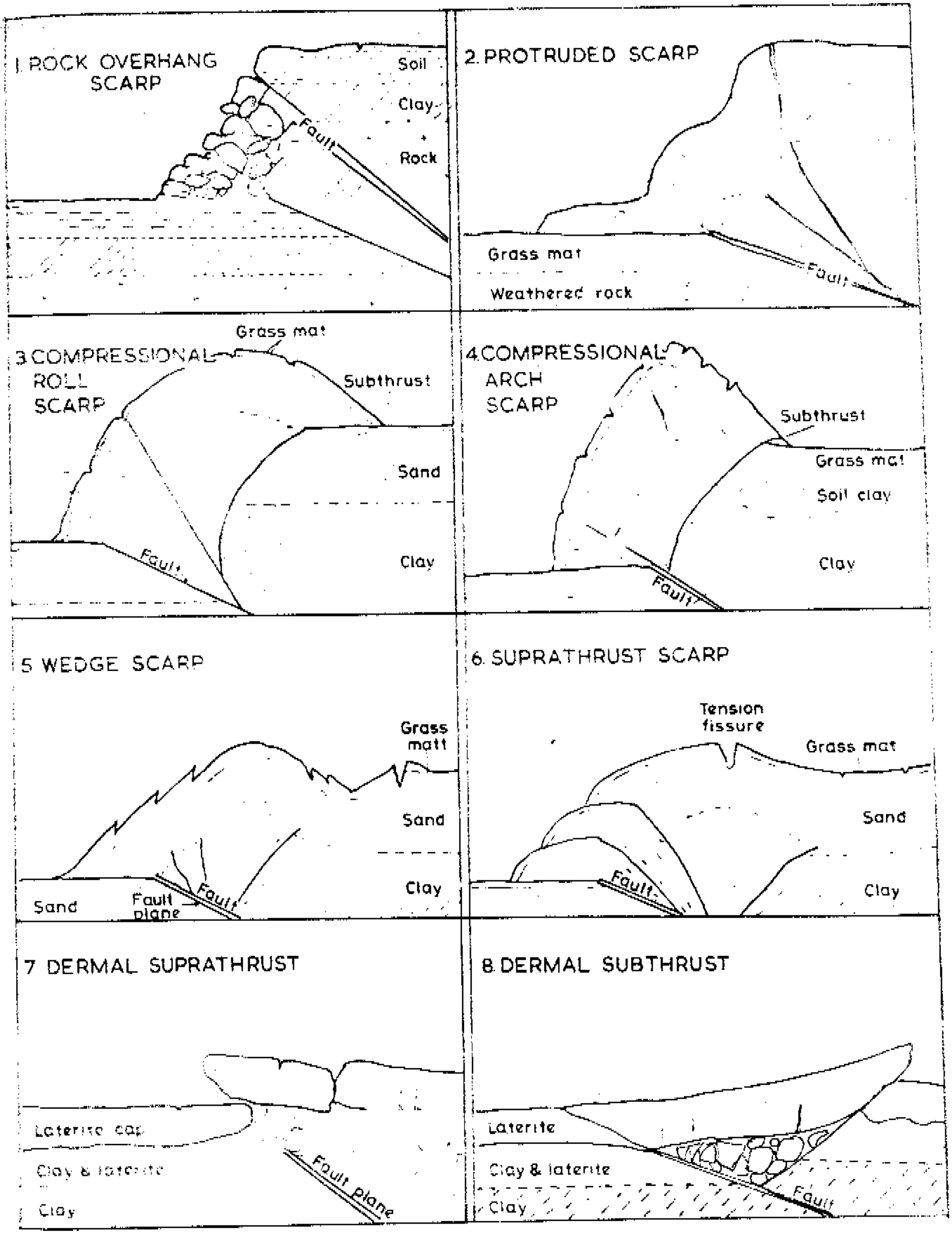
The age of most recent surface rupture is open to question. The ages of the terraces in the area is not well established, although 82,000 ybp appears about the most likely date. Based on the apparent minimum of two rupture events, the faults could rupture once every 40,000± years. Coppersmith (1980) has concluded that a recurrence interval of 5,000 to 20,000 years is much more reasonable for the McKinleyville fault, and 6,000 to 8,000 years appears more reasonable for the Trinidad fault. Coppersmith's conclusion that the two faults he investigated have probably ruptured in the past 20,000 years and may well be Holocene appears valid.

This investigator has some reservations about the mapping of Carver and others (1982a). It appears that the faults portrayed are generalized in several places. Carver himself stated (p.c. 1982) that the approximately located faults are shown with an accuracy of 200 to 500 feet.

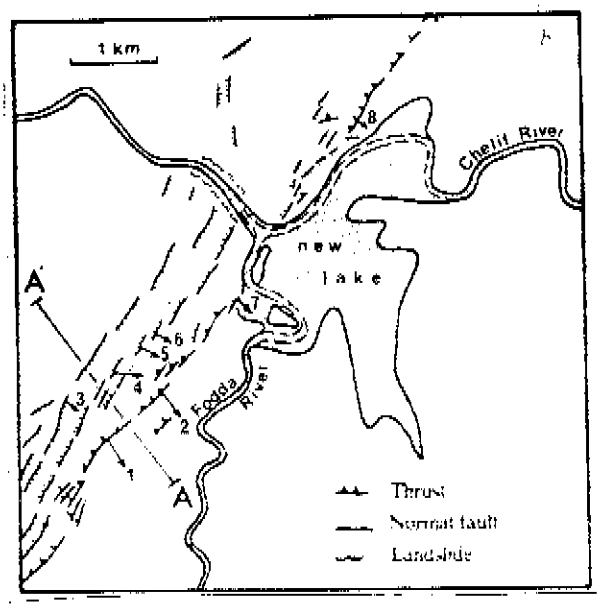
Thus, it would appear that narrow Special Studies Zones may locally be inappropriate. Also, it appears that the faults depicted by Carver and others are based on data of varying quality. Unfortunately, the report accompanying the maps appears to be even more generalized than the maps themselves.

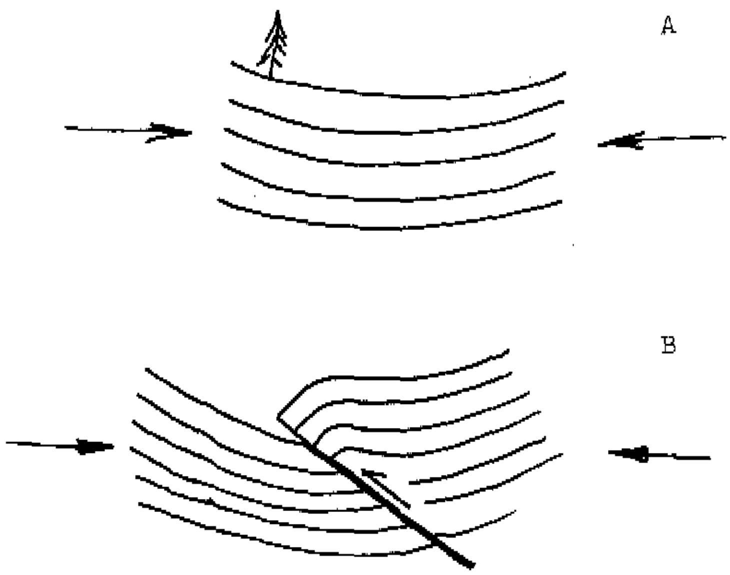
A second concern involves the way that Carver and others (1982a) have interpreted the geomorphic features they identified in the field. It appears, for example, that where a forescarp swale, scarp, and "backscarp" sag or trough have been identified, they have inferred that each feature may be the product of a separate thrust fault trace. However, it is possible that some of these "backscarp" features might be the product of folding, normal faulting, or secondary thrusting along faults that dip back toward the primary thrust. The latter is substantially a larger version of Gordon's (1971) subthrust (see Figure 5). Also, normal faults along which movement has apparently recurred have been identified by King and Vita-Finzi (1981) in the upthrust block near El Asnam. These normal faults generally were subparallel to the primary thrust, and faced both toward and away from the primary thrust (Figure 6). At least some of the features identified by Carver and others could be equivalent (e.g., the northeast-facing scarp identified in sec 18, T7N, R1E). Similarly, some of the fairly linear swales in the uplifted blocks could be the result of broad folding of the terraces and not surface faulting. To my knowledge, however, no significant forescarp swales have been reported in historic thrust fault events. Such features may be the product of folding of the terrace surfaces as illustrated in Figure 7 . Although hypothetical, this mechanism may account for the pattern of imbricate thrusting and outcrop pattern observed by Carver and others on the northeast flank of Fickle Hill.

FER-138. Figure 5. From Gordon (1971).



FER-138. Figure 6. Relationship between normal faults and thrust faults resulting from the 10 October 1980 Algerian earthquake near El Asnam (from King and Vita-Finzi, 1981).





FER-138. Figure 7. Cartoon showing hypothetical way in which forescarp swales might form. (A) Terrace is gradually warped due to regional compression, until faulting occurs (B). Subsequent to faulting the forescarp swale would tend to fill with debris derived from the tilted terrace surface and the scarp.

Some of the features in downtown Arcata appear well-defined and at least one does not. There is some question as to the relationship of the faults reported as once exposed in the roadcut for U.S. 101 and the geomorphic features mapped. There is no data indicating the age of the surface cut and presumably offset by faulting; it could be equivalent to the McKinleyville terrace, but may not be. Also, as with the other faults, the relationship between these postulated faults and the Fickle Hill fault has not yet been well established. However, the features appear similar to those in McKinleyville and, therefore, are inferred to be about the same age and produced by thrust faulting.

Finally, data are lacking that would permit concluding that many of the other features depicted are faults or, if faults, that they are recently active or well-defined.

10. <u>Recommendations</u>

Based on the data summarized herein, the well-defined segments ot the Trinidad, McKinleyville, Mad River and Arcata faults should be zoned. These faults are rather easily avoided in most of the undeveloped or sparsely developed areas since they can be readily recognized by the fault-produced topographic features present.

Except for a few scattered, well-defined secondary faults, no other faults in the study area should be zoned at this time. Faults recommended for zoning are shown on Figures 8A through 8D.

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R.G. 3445, C.E.G. 1029
October 19, 1982

I generally concur with the recommendations. However, much more work needs to be done by others to demonstrate the relationship between the geomorphic features and the sense, magnitude and recency of faulting.
EWH
10/26/82

Fault and Lineament Annotations

F - Fault exposure in Quaternary deposits exhibiting fracture and displacement patterns indicating reverse or thrust movement.

GF - Fault contact between different lithologies.

SZ - Zone of gouge or highly sheared rock in pre-Quaternary deposits.

S - Scarp

MT - Mole track or linear ridge on terrace or geomorphic surface

LD - Linear depression or swale on terrace or geomorphic surface

DT - Displaced terrace or geomorphic surface

WT - Warped terrace or geomorphic surface

SP - Sag pond, pond, or closed depression

SR - Side hill ridge and swale

SD - Saddle

LS - Linear stream or drainage

ID - Incised stream or drainage across lineament or fault

BD - Beheaded stream or drainage with abandoned channel

DD - Diverted, defeated, or disrupted stream or drainage

GWD - Linear ground water barrier - spring line

FER-138. Figure 4. Faults and lineaments of Carver and others (1982a) as compared with the work of others, and air photo interpretation data of Smith (this FER).

Legend of Carver and others (1982a) is attached. Symbols used to plot air photo data are as follows:

dd = disrupted drainage

ld = linear drainage

 = scarp (small)

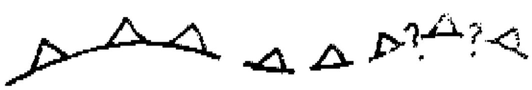
 = scarp (large, as indicated by width of symbol)

Yellow highlights indicate principal fault segments discussed in the text in considerable detail.

Carver and others legend:

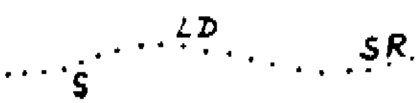
Legend

Low angle reverse or thrust fault cutting Quaternary deposits based on mapped field exposure. Dashed where approximately located. Dotted where covered.



Low angle reverse or thrust fault cutting Quaternary deposits based on field mapped geomorphic expression. Dashed where approximately located. Queried where fault origin for geomorphic features uncertain.

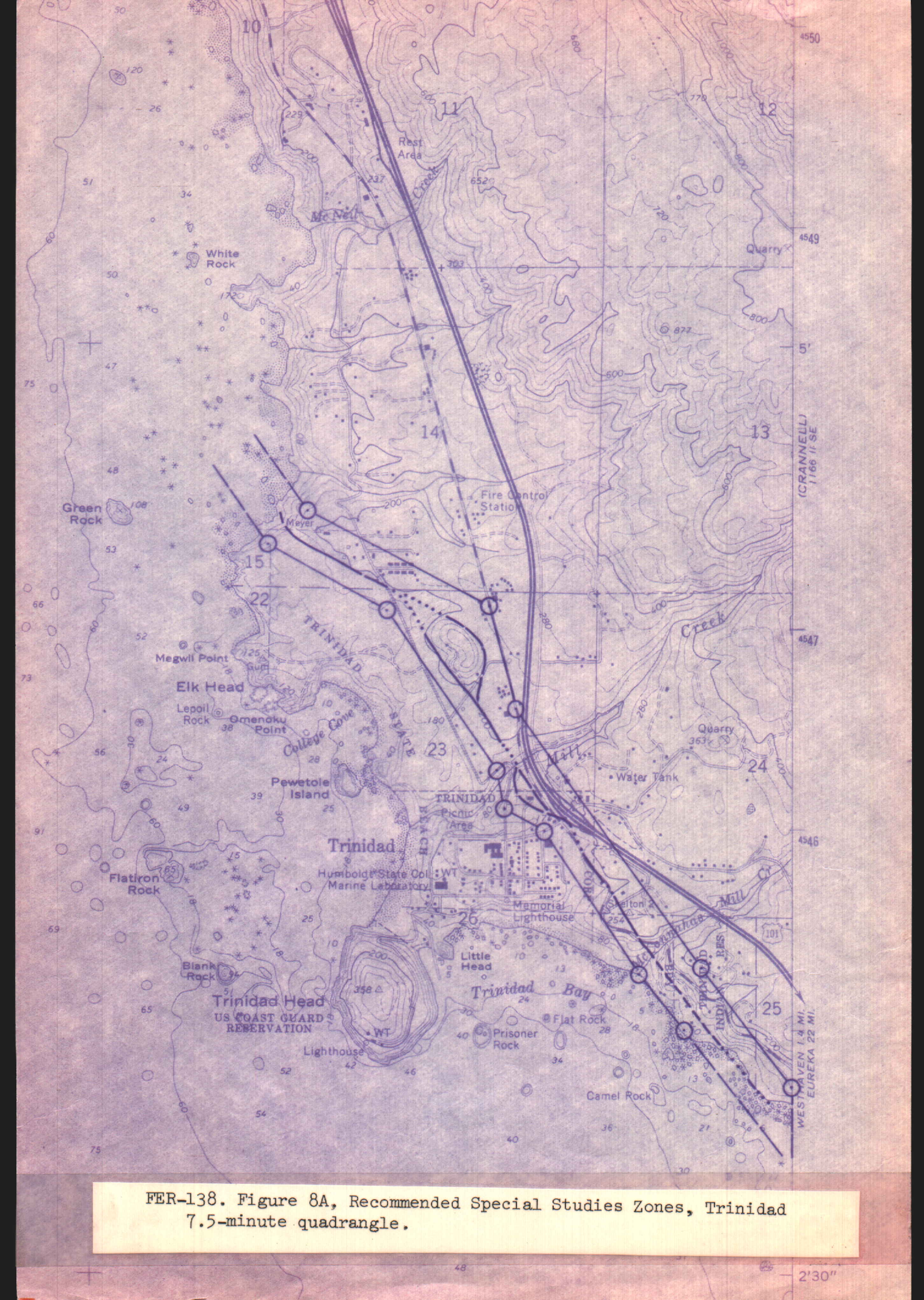
Air photo lineament exhibiting field mapped geomorphic expression characteristic of fault origin.



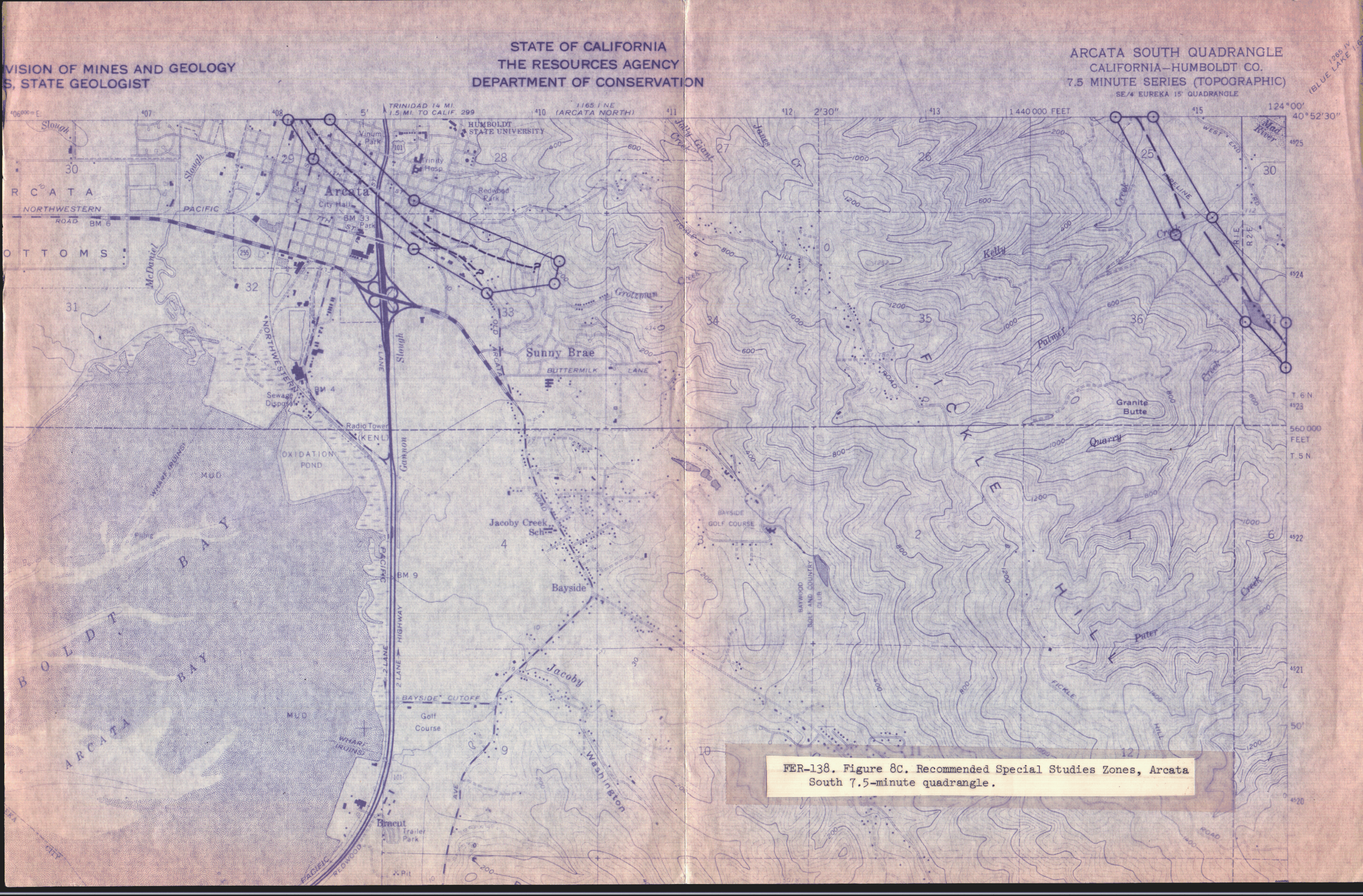
Air photo lineament exhibiting photo interpreted geomorphic expression characteristic of fault origin.

Landsat lineament.

FER-138. Figure 8D. Recommended Special Studies Zones, Korbel 7.5-minute quadrangle.



FER-138. Figure 8A, Recommended Special Studies Zones, Trinidad 7.5-minute quadrangle.



FER-138. Figure 8C. Recommended Special Studies Zones, Arcata South 7.5-minute quadrangle.